Thoracoscopic Vertebral Body Replacement with an Expandable Cage after Ventral Spinal Canal Decompression

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OBJECTIVE: Minimally invasive thoracic anterior surgery using a thoracoscopic approach has evolved to include spinal biopsy, debridement, discectomy, decompressive corpectomy, interbody fusions, and internal fixations. Minimal access techniques can potentially decrease surgical access morbidity and also reduce the time required for recovery and healing. The thoracoscopic approach for decompression, stabilization, and anterior vertebral reconstruction of thoracolumbar fractures is described.

METHODS: In this article and video, we discuss patient selection, surgical positioning, port placement, thoracic level localization, exposure and removal of fractured vertebral bodies, anterior vertebral column reconstruction using an expandable cage, instrumentation, and postoperative management.

RESULTS: The potential advantages of using a minimally invasive thoracoscopic approach include direct trajectory to anterior spine pathology, minimal tissue and rib retraction, and decreased postoperative pain and length of hospital stay. The associated disadvantages include the steep learning curve for the surgeon, the need to operate with two-dimensional visual information and long instruments, and the requirement that one have an experienced surgical assistant.

CONCLUSION: Minimally invasive surgery using a thoracoscopic approach for vertebral body replacement with an expandable cage can be performed safely. Expandable cages facilitate the vertebral body reconstruction via minimal access surgery.

KEY WORDS: Diaphragm attachment, Expandable cage, Minimally invasive surgery, Spinal canal decompression, Thoracolumbar junction, Thoracoscopic surgery

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Traditionally, open thoracotomy or a thoracoabdominal exposure with incision of the diaphragm has been used to address thoracolumbar pathological conditions such as tumor and trauma. These open surgical approaches require extensive incisions, muscle dissection, and rib resections to provide adequate exposure of the anterior thoracolumbar spine. Thoracoscopic anterior spinal surgery has evolved since its first report in 1993 to include spinal biopsy, debridement, discectomy, decompressive corpectomy, interbody fusions, and internal fixations (2, 3, 5, 6, 10). Minimal access techniques can potentially decrease surgical access morbidity and shorten recovery time and promote healing (1, 2, 10). We describe a technique for using thoracoscopic surgery to access the anterolateral spine from T10 to L2 for decompression of the spinal cord with reconstruction after trauma or tumor in select patients.

Criteria for Thoracoscopic Minimally Invasive Surgery

When considering thoracoscopic surgery for anterior spinal cord decompression and reconstruction with expandable cages, we first consider the level of pathology (i.e., T5 to L1), then the position of the great vessels (aorta and vena cava), and finally, patient comorbidities that might preclude single-lung ventilation. Thoracoscopic surgery is considered for patients with pathological conditions located between T5 and L1. Thoracoscopic corpectomy can be performed from T5 to L1 with subsequent placement of anterolateral plating systems into the vertebral body above and below the pathological site from T4 to L2. Although others have reported safe thoracoscopic L2 corpectomy with L3 vertebral body instrumentation, we prefer a retroperitoneal exposure for L2 pathology. The position of the great vessels must be noted on preoperative imaging to determine whether they can accommodate the anterolateral plating system. In general, a right-sided approach is preferred for lesions located between T5 and T10, and a left-sided approach is preferred for lesions between T11 and L2. Specific patient comorbidities that make thoracoscopic surgery unfeasible are pleural adhesions (e.g., from previous chest surgery, trauma, or infection), which make access difficult, or pulmonary conditions that make it unsafe to perform single-lung ventilation (e.g., chronic obstructive pulmonary disease, asthma). Patients with these conditions may be better served with an open thoracotomy or extracavitary approach. In addition to regular spinal studies, preoperative x-ray evaluation should also include posteroanterior and lateral chest x-rays to evaluate for potential pleural fluid, fibrinous membranes, or pleural adhesions.

Surgical Equipment

Thoracoscopic surgery requires a radiolucent table, C-arm fluoroscopy with the ability to easily rotate into the anteroposterior and lateral positions, and a surgical suite large enough to accommodate video monitors on both sides of the operating table. The anesthesiologists must be able to perform double-lumen intubation under bronchoscopic visualization. Surgical equipment includes a 30-degree endoscope (camera), endoscopic portals, combination suction/irrigator, fan retractor, electrocautery, harmonic dissector, and endoscopic vascular clip applier. Hemostatic agents should include thrombin-soaked Gelfoam (Upjohn, Kalamazoo, MI) patties of assorted sizes and liquid Gelfoam in a syringe attached to a long, blunt-tipped needle. Hardware for reconstruction can include a cage system with the ability to expand and collapse as well as an anterolateral plating system. The preference of the senior author (MHS) regarding bone fusion mass is autograft corpectomy bone for trauma or allograft bone plus demineralized bone matrix for tumor. In trauma patients, vertebral body corpectomy bone is an excellent source of autograft bone and is used to pack around the cage for long-term fusion. In tumor patients, the vertebral body is infiltrated with tumor and is unsuitable for autografting. We prefer to spare patients with cancer the morbidity of harvesting autograft bone (e.g., iliac crest, rib), so allograft bone plus demineralized bone matrix is used.

Stages of Surgical Procedure

(see video at web site)

Anesthesia: Double-lumen Intubation

Thoracoscopic spinal surgery is performed under general endotracheal anesthesia with double-lumen endotracheal tube (ETT) intubation. Patients are placed supine on a radiolucent table and intubated with a double-lumen ETT to achieve single-lung ventilation for maximal surgical exposure. Alternatively, a single-lumen tube and an endotracheal blocker can be used if double-lumen endotracheal intubation is impossible. It is imperative that the correct ETT position is confirmed after patient positioning because migration of the double-lumen ETT is common after patients are rolled into the lateral decubitus position. In addition, a Foley catheter and arterial and central venous lines are placed.

Lateral Decubitus Positioning and Fluoroscopic Localization

The patient is turned into the lateral decubitus position on a radiolucent table (*Fig. 1A*). It is important that the patient is secured to the operating table by a four-point support system to the sacrum, pubic bone, scapula, and sternum with adjustable pads (*Fig. 1A*). This allows the table to be moved from side to side during the procedure if necessary. The patient's top arm is placed on a Krause armrest, and an inflatable axillary roll is placed under the axilla (*Fig. 1A*). The legs are flexed slightly to relax the iliopsoas muscle, which aids in endoscopic dissection of this muscle off the lateral aspect of the vertebral body (*Fig. 1B*). C-arm fluoroscopy is then brought into position and used to ensure that the patient and the spine are perpendicular to the operating table. Once the patient is properly positioned, the anesthesiologists should verify proper ETT positioning and begin to deflate the lung.

After lateral decubitus positioning, the level of the lesion or trauma is identified and marked on the skin using lateral C-arm fluoroscopy (*Fig. 1C*). The involved vertebral bodies, discs, anterior spinal line, and posterior spinal line are marked on the skin overlying the lateral chest wall (*Fig. 1C*). Four access sites (portals) are outlined around the level of interest (*Fig. 1C*). Proper positioning of these portals is critical in optimizing working distances, retraction, and image quality. The working portal is centered immediately over the level of interest. The portal site for the endoscopic camera is placed two to three intercostal spaces (approximately 8 cm) above the working portal in the cranial direction along the anterior vertebral body line for thoracolumbar junction pathology; however, in the middle to upper thoracic spine, the camera portal should be placed below the working portal. The suction/irrigation portal is located ventral and slightly above the working portal in a radius that is approximately 8 cm from the working portal. The final portal is used for the lung or diaphragm retractor and is placed ventral and below the working portal. The entire lateral chest well is prepped and draped for a full thoracotomy for the possibility of converting to an open thoracotomy.

Placement of Chest Portals

Once single-lung ventilation has been initiated and verified by the anesthesiologist, a minithoracotomy technique is performed for placement of the port furthest from the diaphragm. This minimizes inadvertent injury to the lung or structures underlying the diaphragm (e.g., liver on the right, spleen on the left). The skin is incised and intercostal muscles are bluntly dissected to identify the underlying rib. A curved clamp is then gently placed over the underlying rib (avoiding the neurovascular bundle running underneath) and the pleural space is bluntly entered. Finger palpation is used to detect any pleural adhesions, and a portal is placed. The 30-degree endoscope is then advanced through the portal to ensure the lung is deflated,

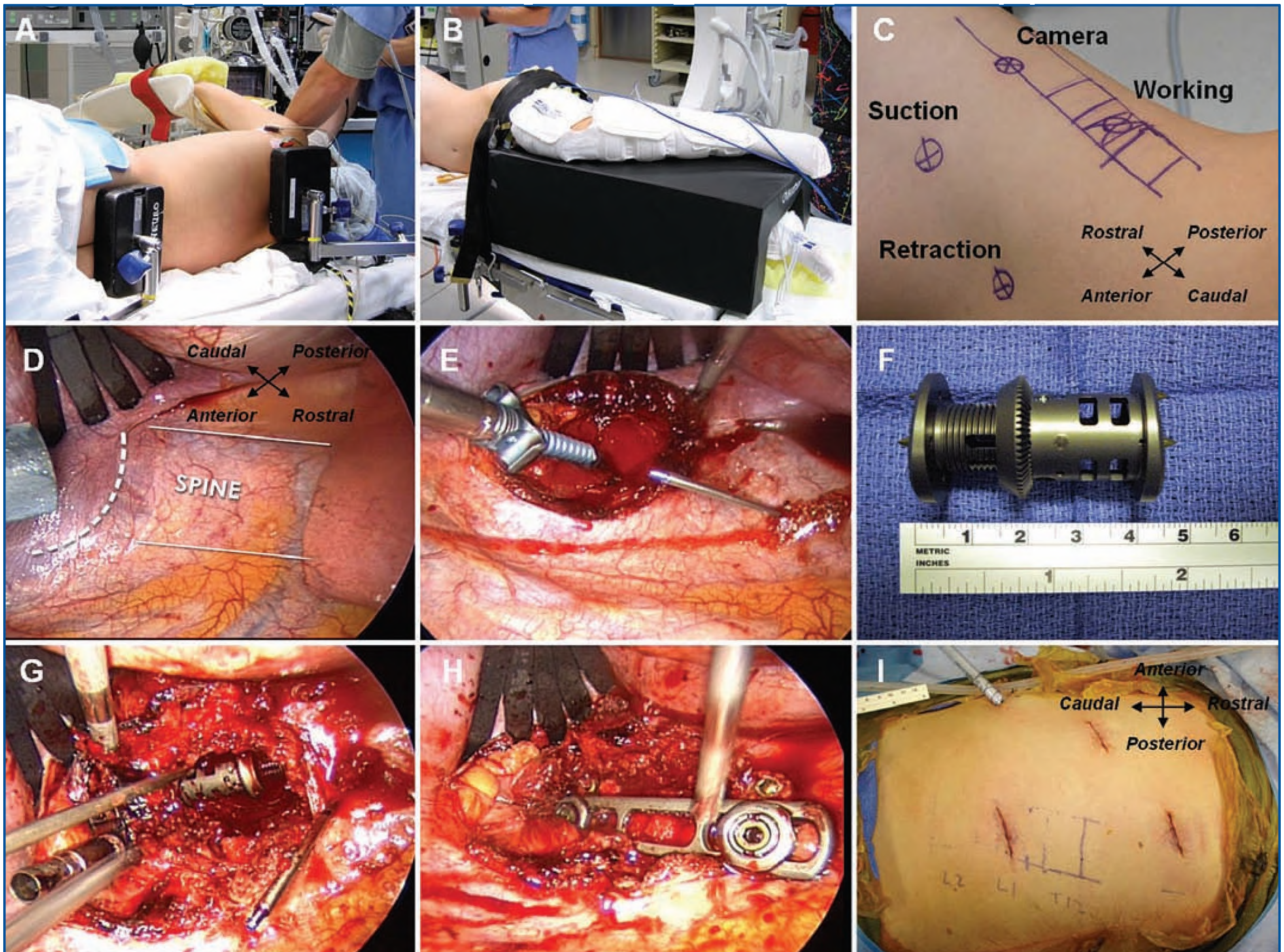

FIGURE 1. *Intraoperative photographs depict positioning (**A–C**), key endoscopic views (**D, E, G**, and **H**), hardware (**F**), and closure (**I**). **A**, the patient is positioned on a radiolucent table in the right lateral decubitus position for a left-sided thoracoscopic approach to L1. The independent arm is in a Krause frame. Adjustable pads at the pubis, sternum, and lower and upper spine hold the patient in position. **B**, the independent leg is slightly flexed at the hip to facilitate iliopsoas relaxation, making it easier to dissect this muscle off the lateral aspect of the vertebral bodies at the thoracolumbar junction. **C**, the level of interest is marked, identifying the vertebral body above and below, and the four chest portals are planned. **D**, endoscopic view of the spine* (solid lines)*. The diaphragm is swept inferiorly with a fan retractor and a diaphragmatic incision is planned* (dotted lines)*. **E**, a Kirschner wire is placed above the planned corpectomy and a polyaxial screw-clamp combination is placed below it. **F**, lateral view of a fully expanded gear-driven cage. **G**, cage is placed and expanded within the central corpectomy. **H**, final anterolateral plate construct. **I**, closure with chest tube exiting the retraction port.*

and the chest cavity is inspected for pleural adhesions. The remaining three portal sites are then placed under direct endoscopic visualization in the same fashion. The key anatomic structures (spine, diaphragm, and aorta or vena cava) are identified and the endoscopic image is oriented so that the spine is parallel to the lower edge of the video monitor (*Fig. 1D*). The camera is placed in the most superior port, the suction/irrigator in the lateral port, and the fan retractor in the inferior-lateral portal for diaphragm retraction. The diaphragm position is noted in relationship to the vertebral body of interest. Usually, the diaphragm inserts at T12/L1, making a diaphragmatic takedown necessary for lesions or injuries located at the thoracolumbar junction.

Diaphragmatic Takedown

The diaphragm is opened if surgical exposure below the insertion of the diaphragm is needed (*Fig. 1E*). A semicircular diaphragmatic incision is placed 1 to 2 cm away from the insertion site where the diaphragm naturally thins out. We prefer to use the harmonic scalpel to make this incision because it does not generate heat or smoke. For exposure of the vertebral bodies of L1 and L2, the diaphragm is opened further caudally, for up to 5 cm (*Fig. 1E*). Splitting the diaphragm exposes the underlying retroperitoneal fat and peritoneum, which are bluntly dissected away from the fascia of the iliopsoas muscle to expose the vertebral bodies. Fluoroscopy verifies the extent of diaphragmatic takedown with the goal of exposing both the vertebral body to be removed and the entry point for the inferior lateral vertebral body screw.

Placement of Posterior Vertebral Body Screws and Spine Instrumentation

We prefer the MACS-TL system (Aesculap, Tuttlingen, Germany) for endoscopic anterolateral stabilization (1). This plating system is designed to secure the anterolateral spine by using a combination of a lateral plate secured to the vertebral bodies with two polyaxial screw-clamp assemblies and two stabilization screws. The vertebral body is divided into thirds in both the anteroposterior and rostral-caudal dimensions on lateral fluoroscopy. The rostral vertebral body entry point is located one-third of the way ventral to the spinal canal and one-third of the way rostral to the corpectomy site. For the caudal vertebral body, the entry point is one-third of the way ventral to the spinal canal and one-third of the way caudal to the level of pathology. These entry points avoid the segmental arteries located in the midportion of the vertebral bodies. Using the radiolucent impaction/targeting device, a short Kirschner wire is placed under lateral fluoroscopy at the entry point. A cannulated awl is then passed over the Kirschner wire to decorticate the entry point. The polyaxial screw-clamp assembly is inserted, and the Kirschner wire is removed after the screw has been engaged. After the polyaxial posterior screws have been placed above and below the site, the clamps are oriented perpendicular to the anterior aspect of the vertebral body, noting the relationship of the screw-clamp assembly with the aorta and spinal canal. An imaginary box is envisioned around the clamps and by keeping surgical instruments within the boundaries of these clamps, mishaps into critical structures (e.g., aorta above or spinal cord below) can be avoided (*Fig. 1, E* and *G*). Also, endoscopy can be disorienting, and the screw-clamp assembly serves as a fixed intraoperative landmark to maintain proper orientation and surgical trajectories. We sometimes choose to place only the inferior polyaxial screw-clamp assembly, which makes it easier to visualize our vertebral body of interest without the superior hardware within the endoscope's line of sight (*Fig. 1E*). In these instances, the Kirschner wire is left in the superior vertebral body for orientation (*Fig. 1E*).

Segmental Artery Ligation and Corpectomy

A pleural flap is elevated with the harmonic scalpel to expose the lateral aspect of the vertebral bodies and the intervertebral discs. Proper identification and hemostatic control of the segmental artery is one of the most crucial portions of the surgery, because the decision to convert to an open procedure must be made if this artery cannot be adequately controlled endoscopically. Segmental vessels cross the midportion of the vertebral bodies from anterior to posterior, deep to the parietal pleura. The harmonic scalpel with a hook tip is used to elevate and incise the parietal pleura, exposing the underlying segmental artery and vein. The segmental artery is carefully exposed using a combination of harmonic scalpel and blunt dissection. Once identified, the artery is ligated with vascular clips, coagulated with bipolar cautery, and divided. This exposes the lateral vertebral body wall and discs.

Segmental arteries are at risk during pleural elevation and screw placement. For the vertebral body below the pathological site, only enough pleura is elevated to expose the screw entry point. If bleeding is encountered at this point, it is controlled with direct compression and the dissection is carried caudally to expose, clip, and coagulate the bleeding artery. If the artery is injured during screw placement, the screw-clamp assembly is tightened to compress the injured vessel. If the latter maneuver is unsuccessful, the screw assembly is removed and the bleeding artery is identified, clipped, and coagulated. Finally, if uncontrolled bleeding is encountered, the decision to convert to an open thoracotomy must be made.

Endoscopic discectomy and corpectomy are performed in a similar fashion as in an open procedure. Adjacent discs are incised with an endoscopic knife and removed with rongeurs. The intervening vertebral body is removed by performing a median corpectomy with straight and curved osteotomes. The corpectomy can be widened with osteotomes or a Midas Rex drill (Medtronic, Fort Worth, TX) with a coarse diamond drill bit. The depth of the corpectomy across midline is verified on fluoroscopy. Once the core of the vertebral body has been removed, the anterior spinal canal is decompressed.

Anterior Spinal Canal Decompression: Identification of Rib Head and Pedicle Removal

The anterior spinal canal is decompressed by identifying and removing the ipsilateral pedicle. First, the ipsilateral rib head is followed to its attachment at the anterolateral spine and removed with a Midas Rex drill. This maneuver exposes the underlying pedicle. The neural foramen is located at the base of the pedicle; removing the pedicle with a drill and endoscopic punches enables direct visualization of the anterior spinal cord. Free bone fragments are then gently pushed into the central corpectomy cavity and removed. Once decompression of the anterior spinal cord has been achieved, reconstruction of the vertebral body is undertaken.

Placement of Cage, Bone Graft, and Anterolateral Plate

We prefer placement of an expandable cage for anterolateral thoracolumbar reconstruction after complete corpectomy (*Fig. 1F*). Expandable cages allow for a tight fit with the ability to expand, collapse, and reposition the cage if necessary. Furthermore, expandable cages can be used for interbody distraction if there is significant kyphotic deformity. The proper cage size is chosen and tapped into place under fluoroscopic visualization while making note of both the anteroposterior and lateral positions (*Fig. 1G*). Cage expansion is achieved and autograft corpectomy bone is packed around the cage. The superior polyaxial screw-clamp system is placed into the superior vertebral body, if this has not already been accomplished.

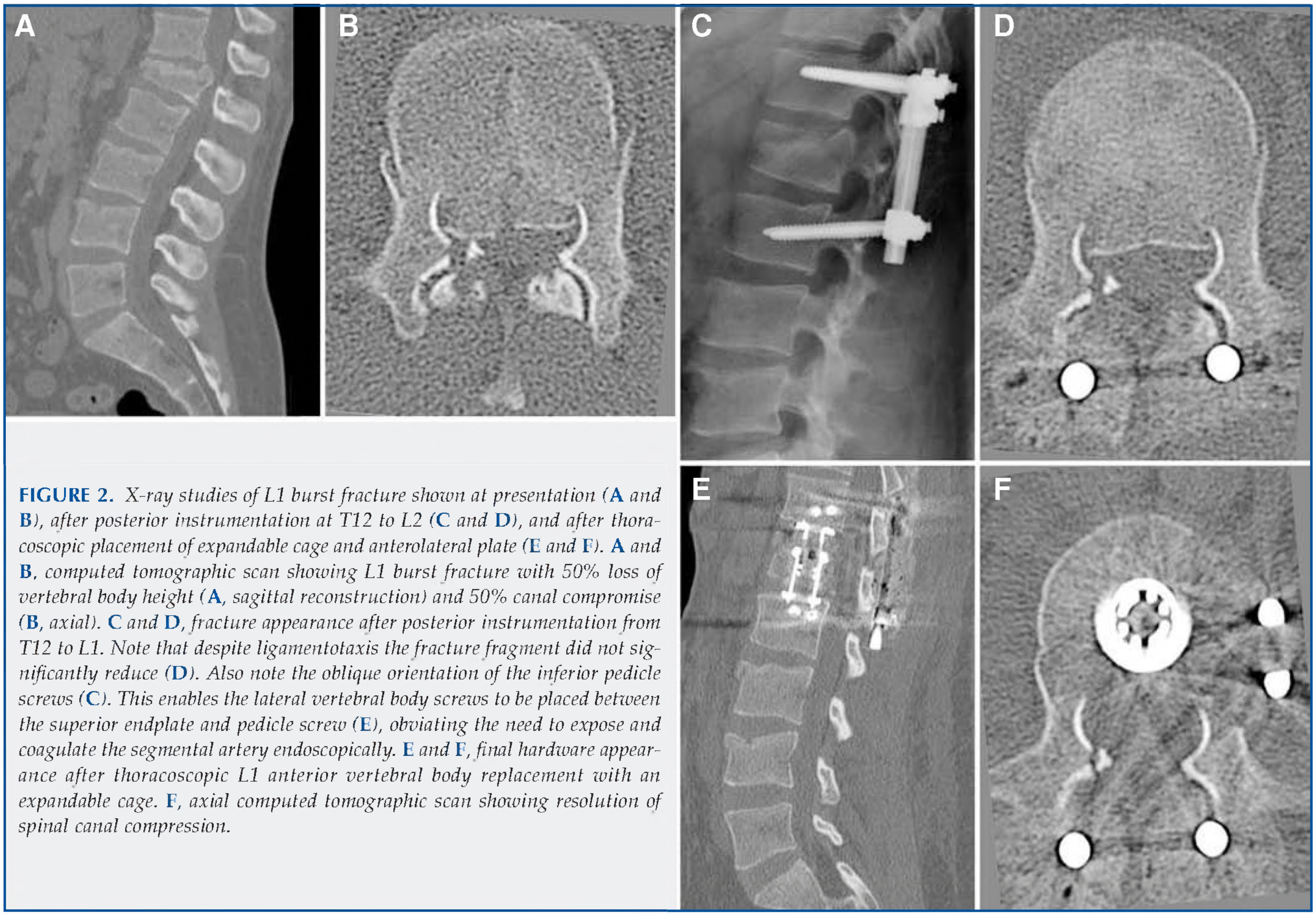

FIGURE 2. *X-ray studies of L1 burst fracture shown at presentation (***A** *and* **B***), after posterior instrumentation at T12 to L2 (***C** *and* **D***), and after thoracoscopic placement of expandable cage and anterolateral plate (***E** *and* **F***).* **A** *and* **B***, computed tomographic scan showing L1 burst fracture with 50% loss of vertebral body height (***A***, sagittal reconstruction) and 50% canal compromise (***B***, axial).* **C** *and* **D***, fracture appearance after posterior instrumentation from T12 to L1. Note that despite ligamentotaxis the fracture fragment did not significantly reduce (***D***). Also note the oblique orientation of the inferior pedicle screws (***C***). This enables the lateral vertebral body screws to be placed between the superior endplate and pedicle screw (***E***), obviating the need to expose and coagulate the segmental artery endoscopically.* **E** *and* **F***, final hardware appearance after thoracoscopic L1 anterior vertebral body replacement with an expandable cage.* **F***, axial computed tomographic scan showing resolution of spinal canal compression.*

Then the anterolateral plate is dropped over the in-place posterior polyaxial screws, and the plate is secured by tightening the posterior screws and placing anterior stabilization screws at each level (*Fig. 1H*). The screw plate assembly is then locked and torqued. All hardware is imaged for proper position with anteroposterior and lateral fluoroscopy.

Placement of Chest Tube, Closure, and Postoperative Care

The diaphragm is reapproximated through the working portal (endoscopic port removed) with long-handled needle drivers and 3–0 Vicryl sutures (Ethicon, Somerville, NJ). The thoracic cavity is irrigated and a small 20-French chest tube is placed to the chest cavity apex through either the inferolateral retractor port or lateral suction port under endoscopic visualization. Lung reinflation is visualized with the camera to ensure all lobes inflate properly. Port sites are closed in multiple layers and the chest tube is secured (*Fig. 1I*). An immediate chest x-ray is obtained to ensure proper lung inflation. The chest tube is initially connected to intermittent wall suction and then to water seal on postoperative Day 1. Daily chest tube outputs are recorded, and the chest tube is removed when output falls below 100 ml per day. This usually occurs on the second postoperative day. A final chest x-ray is used to verify proper lung inflation and the absence of pneumothorax.

Case Report

A 23-year-old man sustained an L1 burst fracture in a fall. The burst fracture had 25 degrees of local kyphotic deformity and 50% canal compromise (*Fig. 2, A* and *B*). During the examination, the patient showed 4 of 5 muscle strength in the lower extremities throughout with decreased sensation below the L3 dermatome. The patient underwent posterior segmental instrumentation from T12 to L2 using pedicle screws and rods (*Fig. 2, C* and *D*); however, postoperatively, the findings from the patient's neurological examination were unchanged with continued lower extremity weakness. Imaging revealed no significant change in canal compromise despite correction of the kyphotic deformity and distraction between pedicle screws for ligamentotaxis (*Fig. 2D*). Because of continued neurological deficit, we elected to perform an anterior vertebral body decompressive procedure with reconstruction using a thoracoscopic surgical approach. The patient underwent a left-sided L1 corpectomy for anterior spinal canal decompression. A gear-driven Globus expandable cage (Globus Medical, Audubon, PA) was placed, morcellized vertebral body autograft bone was packed around the cage, and an MACS TL anterolateral plating system was used. Postoperative neuroimaging demonstrated spinal canal decompression and hardware position (*Fig. 2, E* and *F*).

DISCUSSION

Anterior thoracic vertebral body reconstruction for trauma or tumor involves corpectomy for decompression of neural elements and placement of hardware to reconstitute the anterior weightbearing stability of the spine. The anterior vertebral column carries most of the axial load of the spine and reconstruction is important in maintaining normal spine biomechanics and preventing posterior construct hardware failure (7, 9, 13). Biomechanical and clinical studies support combined anterior and posterior constructs for maximal stability to the thoracic and thoracolumbar spine (7–9, 12, 13). Options for anterior vertebral body reconstruction include autograft bone (e.g., iliac crest), autograft bone (e.g., fresh cancellous bone), ceramic/glass, carbon fiber spacers, and titanium cages (9, 12, 13). Recently, expandable titanium cages have been developed for vertebral body reconstruction with the advantage of ease of placement, broad endplate surface, and the ability to expand in situ for deformity correction (13). Interestingly, most expandable cages become incorporated within the ventral bony fusion mass by 20 months with excellent long-term kyphotic correction (4). Previously, cage placement through thoracoscopic ports was difficult because of cage size and the difficulty in cage repositioning with endoscopic instruments. These problems are largely overcome with new-generation expandable titanium cages.

Thoracoscopic operative hazards can be overcome by observing a careful technique for patient selection for single-lung ventilation, positioning the spinal column perpendicular to the bed for good fluoroscopic visualization, and correct placement of portals to minimize "fencing" instruments. In addition, clip ligation and coagulation of the segmental artery away from its aortic origin can help prevent retraction of a bleeding arterial stump, and placement of the screw-clamp assembly perpendicular to the spinal canal will provide a fixed intraoperative landmark. Similarly, corpectomy followed by spinal canal decompression provides a cavity in which compressive spinal cord lesions can be removed away from the spinal cord.

The advantages of a minimally invasive thoracoscopic approach include a direct trajectory to anterior spine pathology, minimal tissue and rib retraction, and decreased postoperative pain and hospital stay (10, 11). Disadvantages include a steep learning curve, the need to operate with two-dimensional visual information, long instruments, and the need for an experienced assistant (11). Realistically, an endoscopic surgeon needs to have a high-volume spine practice to become proficient with this technique; without extensive experience, operative times can still be longer then traditional open thoracic approaches. Overall, minimally invasive surgery is safe and enables direct access to anterior spine pathology with decreased surgical morbidity.

CONCLUSION

Thoracoscopic anterior vertebral body reconstruction with expandable cages can be performed safely. Future studies will focus on patient outcomes after minimally invasive techniques for anterior vertebral body reconstruction.

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Acknowledgments

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COMMENTS

The advantage of an anterior approach to the thoracic spine is direct decompression of the spinal canal, reconstruction of the anterior column, and stabilization in one seating. The advantages of a thoracoscopic approach include smaller incisions, less muscle dissection, and avoidance of a rib resection and rib spreading. The complications that occur with an anterior approach include injury to the lung, major vessels, ureter, sympathetic chain, neural elements, and intra-abdominal organs, and accidental entrance into the peritoneum. Although potential complications may be attributed to the surgeon's unfamiliarity with this approach, Ragel et al. describe this thoracoscopic approach for decompression and stabilization with an expandable cage. Their detailed approach assists other surgeons in the understanding of the anterior thoracic anatomy and surgical techniques.

Max C. Lee
Daniel H. Kim
New Orleans, Louisiana

Ragel et al. describe the nuances for performing a corpectomy and placing a cage and plate via the thoracoscopic approach to treat abnormalities of the thoracic and upper lumbar spine. They describe the perils and pitfalls of the procedure. As the authors rightly emphasize, thoracoscopic corpectomy requires a steep learning curve. The expandable cage has made this procedure somewhat more attractive. In the past, it was difficult to place a large cage through the thoracoscopic tube. Thoracoscopic corpectomy is a sophisticated procedure that requires superb surgical expertise. The authors have provided us with excellent details of this procedure.

Volker K.H. Sonntag
Phoenix, Arizona

This article describes thoracoscopic techniques, including the use of an expandable cage for reconstruction of traumatic burst fractures of the thoracolumbar vertebrae. Technical nuances are well-delineated. Expandable cages seem ideal for thoracoscopic application, as they can be placed through a small portal, and the size can be manipulated to fit the vertebral body defect in the chest cavity. An additional advantage of expandable cages in trauma reconstruction is the facility of kyphotic deformity reduction. The major disadvantages are the reduction in surface area for bone graft and potential arthrodesis and the inability to image the spinal canal using magnetic resonance imaging despite the use of titanium. An important technical nuance in the discussion is turning the chest tube suction off in the presence of a spinal fluid leak. Chest tube suction may create difficulty in obliterating a cerebrospinal fluid fistula, and, in the presence of a pneumothorax, may lead to pneumocephalus.

Mark H. Bilsky
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Ragel et al. describe a thoracoscopic vertebral body resection procedure that is followed by placement of a titanium expandable cage. It is apparent that the authors have good skill and excellent experience with this technique in a large number of patients. My concern is that an expandable cage used in this manner has the potential to violate Wolf's law. By placing bone in the cage and then expanding the cage, the bone graft is actually unloaded from any compressive forces, and in so doing, from a biomechanical standpoint, the material inside the cage might be subject to forces favoring resorption rather than fusion. Although this article is a technique description, and a good one at that, long-term fusion results will need to be assessed to determine whether radiographic bony arthrodesis is able to be ultimately achieved with this technique.

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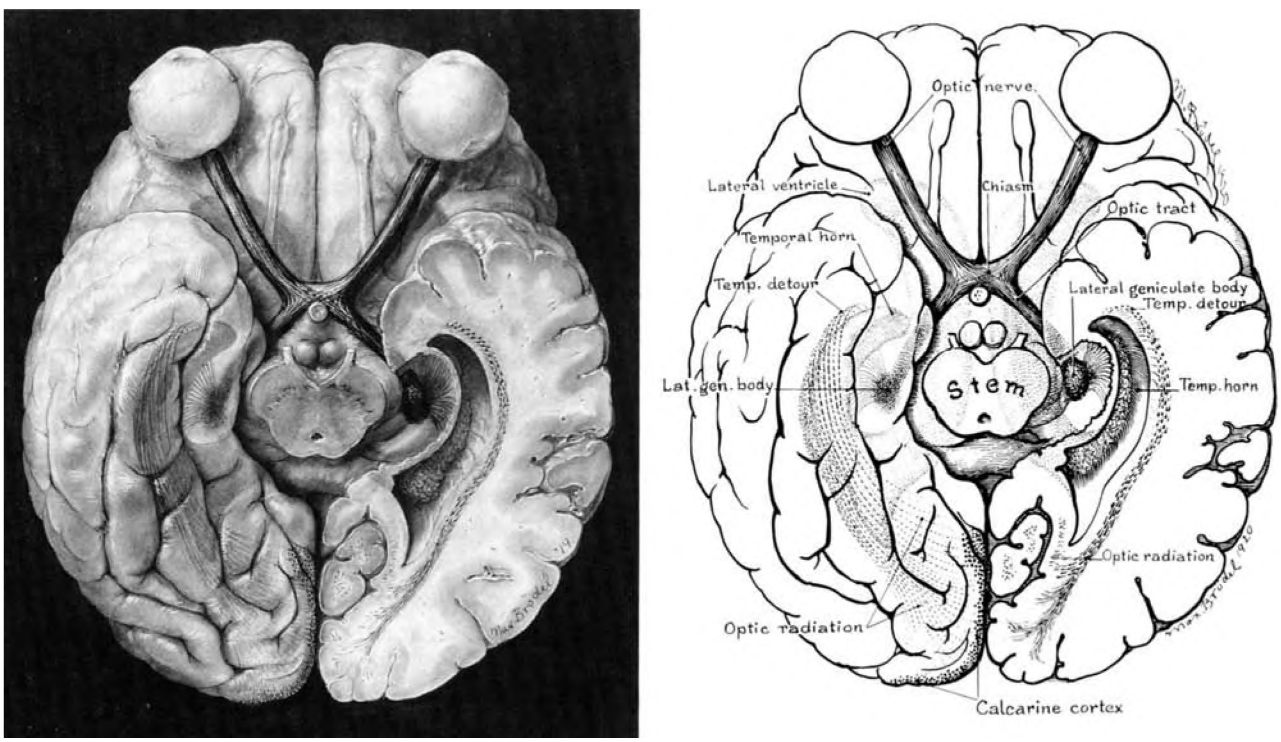

Harvey Cushing requested the following Max Brödel illustrations of the visual pathways for his manuscript, "Distortions of the Visual Fields in Cases of Brain Tumor," that was subsequently published in the *Transactions of the American Neurological Society, 1921*. From Crosby RW. Cody J: *Max Brödel: The Man who put Art into Medicine*. New York, Springer-Verlag, 1991.